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## **CARBON DIOXIDE EMISSION ASSOCIATED WITH THE PRODUCTION OF PLASTICS - A COMPARISON OF PRODUCTION FROM CRUDE OIL AND RECYCLING FOR THE DUTCH CASE**

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### **Abstract**

Literature data show that in general, plastics produced through the mechanical recycling route involve less carbon dioxide emission than when produced from crude oil. A review of readily available data shows that road transport of untreated waste plastics account for a significant portion of the carbon dioxide emission generated during recycling. Therefore, much carbon dioxide emission can be saved by optimizing the logistics in the recycling of plastics.

On the example of polyolefins originating from household packaging waste, this paper attempts to compare two different scenarios of mechanical recycling to the production of plastics from crude oil as a reference. The first scenario deals with packaging waste from selective collection, in which data from the current practice of the German DSD system were translated for the Dutch situation. In the second scenario, plastic packaging recovered from household waste using mechanical separation techniques is considered. It is assumed in the second scenario that the plastics are separated from the rest of the household waste and processed further to a compound close to the site at which the rest of the waste is disposed of, e.g. at an incinerator plant or landfill site. This scenario is assumed to involve the least of road transport of existing recycling options. The data presented in this paper represent the results of a preliminary study.

*Key words:* carbon dioxide emissions, plastics, recycling

### **1. Introduction**

Inspired by the implementation of separate collection systems for packaging waste in neighbouring countries, The Netherlands also started pilot projects with separate collection in 2007 (Nedvang system), in order to gain experience for an intended country-wide introduction. On the other hand, several household waste sorting plants are operated in The Netherlands, some of which have recently started producing plastics fractions recovered from household waste using mechanical separation techniques. These waste sorting plants are located close to municipal waste incineration plants (MWI), which receive the residue streams from the waste sorting plants. Therefore, the present Dutch situation

offers a good case to compare the two above described approaches of recycling schemes for plastic packaging waste.

Several studies were devoted to the comparison of different recycling scenarios of plastic packaging waste using different performance parameters in the near past (Ansems and Ligthart, 2005; Krutwagen and van Ewijk, 2008; Öko-Institut e.V. report, 2000; Shonfield, 2008). These studies agree that in general, mechanical recycling of plastics involve less carbon dioxide emission when compared to land-filling the plastic waste or incineration in a standard MWI plant having a thermal-to-electrical energy conversion efficiency of approx. 20-22%, and using virgin resins for new products (Ansems and Ligthart, 2005; Krutwagen and van Ewijk, 2008;

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Öko-Institut e.V. report, 2000; Shonfield, 2008; Tempelman, 1999). It has been pointed out, though, that this environmental benefit only exists when the recycled plastics replace virgin resins (Shonfield, 2008). This benefit turns to an environmental burden, however, when the recycled plastics are applied to replace wood or concrete. In other words, downcycling plastics, e.g. to plastic lumber, does not make sense from an environmental point of view. It is, therefore, important that a maximum portion of the mechanically recycled plastics are of sufficiently high quality to compete with virgin resins.

It has been assumed in most previous studies that foils recovered from municipal waste will mainly be used as a refuse derived fuel (RDF) (Ansems and Ligthart, 2005; Krutwagen and van Ewijk, 2008). This is because available mechanical recycling techniques are usually not feasible for this fraction due to the high costs associated with cleaning and separation of post-consumer foils. This fact is a severe drawback of existing recycling scenarios, because more than half of the plastics contained in household waste are foils (Krutwagen and van Ewijk, 2008; Private communications - VAGRON 2008, 2009). However, it has been recently shown that a novel compounding technology can turn mixed plastic foils recovered from household waste into recycled compounds that compete with virgin resins in many large high-end applications, e.g. transport pallets and waste collection bins, at very competitive prices by using modulus-improving additives, if necessary (Private communications - Plastinum Polymer Technologies, 2008-2009).

## 2. Objectives

By focusing on the carbon dioxide balance, this paper provides a comparison between two scenarios for the production of secondary polyolefins from packaging waste for the Dutch situation. The two scenarios are selective kerbside collection and separation from household waste. In order to show the potential of mechanical recycling and to anticipate for technological development, there were used data of the latest technologies in mechanical separation and compounding, rather than average current practice. The results were compared to the carbon dioxide balance of primary polyolefin resin production. As the Dutch Nedvang system for the separate collection of packaging waste is in its infancy today, available data from the German DSD programme and translated to the Dutch situation were used.

## 3. Where go recovered plastics today?

The Belgian governmental organization for waste, OVAM, estimates that 13% of the plastic waste generated in Belgium is mechanically recycled at present, from which only 1/3 in Belgium itself (<http://www.ovam.be/jahia/Jahia/pid/554?lang=null>).

A brief survey among a few waste logistic centres in The Netherlands and in North-West

Germany reveals that the majority of the post-consumer mixed rigid plastic waste collected at regional waste consolidation centres are baled and transported to China at present. Obviously, Chinese recyclers pay better prices than their local or regional competitors in Europe. It appears that this situation is for a significant part a result of differences in quality requirements that converters set on recycled plastics in applications where virgin resins are to be replaced. We assume that in both China and Europe, converters pay similar prices for virgin resins. However, by pointing to the high quality standards of their customers, European converters seem to require a larger price discount for taking the risk of quality problems by using recycled plastics than their Chinese counterparts. This finding leads to the conclusion that both the quality of recycled plastics and the amount of constant quality offered have to be increased to a higher level to compete on the European market. A solution can be expected from technological improvements in separation and extrusion, as labour costs are high in Europe at present.

## 4. Carbon dioxide emission in waste transport

By assuming domestic recycling and hence short transport distances, some previous studies conclude that the carbon dioxide emission associated with the transport of plastic waste has a moderate contribution to the total carbon dioxide balance in their recycling (Ansems and Ligthart, 2005; Krutwagen and van Ewijk, 2008). This appears an underestimate considering the current practice of plastic recycling in Europe as briefly outlined above.

A study from 2008 calculated the carbon dioxide emission associated with the transport of plastic packaging waste collected in the UK to China (WRAP, 2008).

The study estimates that 158-230 kg CO<sub>2</sub>/ton recovered plastic is generated during the transport of mixed plastic bottles. This figure covers all required transport steps from regional waste consolidation centres (transfer stations) in the UK to plastic recyclers in China, but ignores transport required for kerbside collection and transport to waste the consolidation centres (WRAP, 2008). The report points out that approx. 80% of the carbon dioxide emission associated with the transport of plastic waste can be attributed to transport by ship to China. The above figures reduce to approx. 25 – 50 kg CO<sub>2</sub>/ton plastic, if one ignores the emission incurred during transport by ship. There is some argument to do so due to the current trade imbalance between China and the UK, as a consequence of which a large portion of the cargo ships return empty to China (WRAP, 2008).

## 5. Competing approaches

Since the introduction of the separate collection system of packaging waste in Germany – known as Duales System Deutschland or DSD – in

1991, several countries have implemented similar collection schemes, such as Belgium, Austria, UK and Canada. Note that in some countries, plastic packaging is collected together with other packaging materials (such as metals and tetra paks), e.g. in Germany and Belgium. Other collection systems, such as currently operational in Canada and as intended for The Netherlands, collect plastic packaging separately.

Originally, a major argument for setting up separate collection systems for plastic packaging material was the general perception that the opportunities of mechanical recycling of plastic packaging materials recovered from household waste are limited. A TNO study carried out for the Association of Plastics Manufacturers in Europe (APME, currently named Plastics Europe) in 2001 based on an eco-efficiency analysis concluded that from an eco-efficiency point of view, the optimum for plastic packaging waste lies at 15% mechanical recycling and 85% incineration with energy recovery (TNO, 2001).

On the other hand, it was broadly believed that separate collection of packaging waste should yield pre-concentrated, sufficiently clean fractions that should be suited for recycling. No doubt, the separate collection systems introduced in different countries together with recycling rate targets laid down in national legislations have given a boost to technology development. However, the development of mechanical separation systems for household waste sorting has not been standing still in the meantime and have also profited from the development of recycling technology, such as sensor sorting systems.

For example, the Dutch company Essent Milieu at his Vagron plant in Groningen has been operating a household waste sorting plant at a capacity of 45 tons/h for over 30 years (Private communication- VAGRON 2008-2009). This plant – which has been much improved over the years – recovers plastic-foils using wind-sifting and rigid plastics using a near-infrared sorting device. There are two other plants in The Netherlands and several more abroad that successfully apply mechanical separation of household waste similar to the Vagron plant. This fact has recently placed this proven concept back into debate as a competing approach to the selective collection of packaging waste (Ansems and Ligthart, 2005).

Based on the experiences gained during the last one and a half decade in both selective collection and household waste sorting, we can list several arguments that advocate in favour of the latter:

1. It has been shown that a significantly larger portion of plastic waste generated by consumers can be recovered by mechanical sorting of household waste than by separate collection (Ansems and Ligthart, 2005). Vagron reported that using single-stage separation steps, they are currently able to recover over 50 wt-% of the plastics contained in household waste (Private communication- VAGRON 2008-2009). Note that this approach bears a potential

to increase the recovery rate by applying multi-stage separation. A simple calculation shows, on the other hand, that the 600.000 tons of plastic packaging waste annually collected in the DSD programme covers approx. 20 - 25% of the plastic waste discarded by households in Germany (Ansems and Ligthart, 2005; <http://www.gruener-punkt.de/de/journalisteninfo/recherche>). This figure can be regarded as an equilibrium value after 16 years of collection.

2. Whereas separate collection systems largely rely on and are limited by the co-operation of consumers, improvements in waste separation are truly technology driven. For example, plastic packaging waste collected by enthusiastic Dutch consumers during the first year of pilot trials of the Nedvang collection system yielded surprisingly clean plastic streams (Private communications - Plastinum Polymer Technologies, 2008-2009). After 16 years of DSD, however, the yellow bag collected in Germany contains on the average approx. 35 wt-% non-recoverable organic residues, such as food rests, wood and paper (Private communication - Plastinum Polymer Technologies, 2008-2009). This fact contradicts the wide-spread belief that selective collection yields cleaner plastics than waste sorting.

3. The recycling of plastic packaging waste based on the mechanical separation of household waste involves a simpler logistic system (Ansems and Ligthart, 2005), which in addition involves significantly less carbon dioxide and other emissions (Krutwagen and van Ewijk, 2008).

4. Preliminary tests using a novel compounding technology indicate that recycled compounds made from selectively collected DSD plastic packaging waste often have a strong, unpleasant smell and require significant amounts of deodorant additives during compounding to suppress it (Private communications - Plastinum Polymer Technologies, 2008-2009). On the other hand, compounds made from plastic packaging recovered from household waste are virtually odourless or have a weak smell at most. This finding might be surprising, but can be explained by the differences in the average time elapsed between discarding the plastic packaging and its processing: it takes a few days to a week for household waste, but amounts to 3 to 4 weeks for separate collection (Kok and Nas, 2008; Private communications – VAGRON, 2008, 2009) For The Netherlands, a collection frequency for kerbside collection of plastic packaging waste of once in two weeks to once in a month is suggested (Kok and Nas, 2008; SITA, 2009).

## **6. Separation technology**

In order to produce high-purity granulate from polymers present in household waste, of a quality comparable to materials presently produced from post-industrial waste, one of the options is to use a sink-float technology that is sensitive to very small differences in density of the materials. At the same

time, in order to be economically and ecologically sound, such a process should recover most of the polymers into useful products and minimize process residues.

An emerging technology that may achieve this is Magnetic Density Separation (MDS) (Bakker et al., 2009). The technology is potentially very cheap because it separates a complex mixture into many different materials in a single process step, using one and the same liquid. The entire separation is performed as the mixture flows through a magnetic field and segregates in a few seconds into as many different layers as there are products. The process liquid is water-based and can be recovered mechanically down to about 5 kg of liquid per ton of de-watered product for rigid plastics. Since each kg of process liquid contains as little as 6 grams of iron oxide (the active material for the separation), most applications of the polymer products do not require that such a minor amount of liquid be washed from the plastics. Therefore very low costs are associated with the recycling and quality control of the liquid, usually one of the expensive steps in advanced sink-float separations.

MDS is very sensitive to small differences in material density, provided that the turbulence in the liquid can be accurately controlled. Results obtained with a small MDS laboratory setup have shown that PP can be separated cleanly from PE. In another experiment a mixture of fine minerals was efficiently separated into five different products in a single channel. In order to become a practical method for polyolefin separation, MDS technology must reach an accuracy of 10 kg/m<sup>3</sup> at commercially interesting production rates of 5 tons/h or more. To achieve this, flow geometries must be chosen so as to develop sufficient turbulence to create a free suspension of particles but not enough to destroy the segregation of materials in the separation zone.

Despite the potential accuracy of MDS, some contamination of the products is unavoidable due to the natural overlapping of density ranges of the different materials. The extent to which this problem occurs depends on the composition of the actual feed material and so it cannot be solved in the design stage.

Present research focuses on ultrasound technology to create a precise and on-line assessment of the composition of product streams to make the best possible products from any given feedstock.

## 7. Methodology and assumptions

### 7.1. Steps required for recycling plastic packaging waste

In the waste sorting scenario, the following steps were considered in this study:

1. Regular kerbside collection of household waste by diesel-powered trucks equipped with a hydraulic waste compactor;

2. Transport to a waste processing facility either directly by waste collection trucks for short distances of approx. <10 km or after pre-collection at a transfer station for long distances of approx. >10 km. For the latter, diesel-powered trucks carrying compacted waste are assumed;

3. Recovery of plastics at a household waste processing facility using mechanical separation techniques;

4. Transport of the recovered plastics by diesel-powered trucks to an integrated plastic recycling facility;

5. Producing of compounds from the recovered plastics in an integrated plastic recycling facility by cutting, washing, drying and extrusion/compounding.

In the selective collection scenario, the considered steps were:

1. Kerbside collection of plastic packaging waste (yellow bag) by diesel-powered trucks equipped with a hydraulic waste compactor and transport to a regional consolidation centre (transfer station) by the same vehicle;

2. Transport from the transfer station to a plastic waste sorting facility by diesel-powered trucks carrying compacted waste;

3. Sorting of plastics at a plastic waste sorting facility using mechanical separation techniques; it is assumed that this step is based on multiple-stage near-infrared sensor sorting technology;

4. Transport of the separated plastic fractions by diesel-powered trucks to an integrated plastic recycling facility;

5. Producing compounds from the recovered plastics in an integrated plastic recycling facility by cutting, washing, drying and extrusion/compounding.

### 7.2. Road transport

The fuel consumption of diesel trucks during kerbside collection is significantly higher than during long-distance travelling. This is due to the frequent start and stop operations of the heavily equipped truck and to the energy required for the hydraulic waste compactor on board. For kerbside collection in cities, a fuel consumption of 400 litre diesel per 100 km has been reported by TNO (Ansems and van Gijlswijk, 2007). This fuel consumption figure was used in this study for the kerbside collection route. When collecting household waste, the average net cargo load is 8.5 tons per truck (ARCG, 2009).

However, when plastic packaging waste is collected separately, a truck load of only between 2 and 3 tons can be reached with the same type of truck (Kok and Nas, 200). It is assumed a net average cargo load of 2.5 tons per truck in our calculations. For long-distance transport of the loaded waste collection trucks, an average fuel consumption of 30 litres per 100 km was assumed. For road transport, we calculated emissions due to the combustion of diesel fuel only, ignoring emissions associated with the production of the fuel.

### 7.3. Fragmentation, cleaning and extrusion of plastics

Reliable data on the energy consumption of fragmentation and cleaning of plastic waste and extrusion of the clean plastic flakes are key factors in determining the carbon dioxide emission associated with the recycling of plastics. This is because these are the most energy consuming steps in the recycling chain by far. Unfortunately, it proved to be difficult to ascertain reliable figures on these steps, which is partly due to the lack of accessible information. In addition, the specific energy consumption in cleaning and extrusion varies widely, depending on design and operational parameters, e.g. throughput, type of input and the technology applied. The data on cleaning of waste plastics and extrusion used in this study represent our current best estimates.

Note that due to their small wall thickness, plastic foils and films require considerably more energy for cleaning per ton throughput than thick plastic flakes. A foil/film washing line of basic technology and with a design throughput of 500 kg/h require 400 kWh/ton including hot washing, thermal drying and foil-compacting, whereas a plastic bottle washing line of the same capacity only consumes 200 kWh/ton (also including hot washing and thermal drying). It appears that these data mark the upper limit in plastic washing due to the small throughput and basic technology applied. As a rule of thumb, the actual energy consumption is 50 to 60% of the installed power for plastic washing lines (Private communications - Envirotec BV, 2009; Private communications - Plastinum Polymer Technologies, 2008-2009).

Proceeding from a mix of 65 wt-% foils and 35 wt-% rigids in plastic packaging waste recovered from household waste (Private communications - VAGRON 2008-2009) and an actual throughput of 2 ton/h per processing line, we estimate the average power consumption in the cleaning and fragmentation step using state-of-the-art technology at 200 kWh/ton.

In general, double-screw extruders consume less energy than single-screw machines, while the specific energy consumption drops progressively with increasing unit throughput. In turn, the actual throughput of extruders depends on the design throughput, the smelt filtration technology applied and the purity of the input flakes. Obviously, non-melting impurities in the feed material will increase the filter load and thus reduce the throughput.

According to AKG Polymers – a Dutch plastic converter operating several single and twin-screw extruders of different capacity –, the actual power consumption of their single screw extruders having a nominal throughput of 500 kg/h range between 370 and 750 kWh/ton plastic produced with an average corrected for plant-throughput of 540 kWh/ton with recycled polyolefin flakes as an input (Private communications - AKG Polymers BV, 2009). On the other hand, the largest twin-screw extruder of AKG with a nominal throughput of 1200 kg/h only consumes 290 kWh/ton plastic produced with the

same type of input material. A WRAP study reports 240 to 300 kWh/ton for extruders without specifying type and capacity of the extruder and the type of input material (Shonfield, 2008).

Further, for state-of-the-art, 1500 kg/h twin-screw extruders an energy consumption of approx. 200 kWh/ton was reported by Envirotec (Private communications - Envirotec BV, 2009). For the purpose of recycling plastic packaging waste, we assume large-scale operations and state-of-the art extruders. Therefore, we used an estimated average specific energy consumption of 240 kWh/ton in extrusion for the calculations in this study.

It has been reported that the net energy expenditure of producing recycled PP from post-consumer car batteries in the German battery recycling plant in Braubach is 1.69 MJ/kg, or 470 kWh/ton by assuming that only electrical energy is spent in the processes (Tempelman, 1999). This figure from the year 1998 includes all processing steps required including fragmentation, washing, drying and extrusion of the plastic material.

### 7.4. Electricity production

From literature data, we estimate the current carbon dioxide emission in electricity generation in The Netherlands at 0.54 kg CO<sub>2</sub>/kWh based on average electricity generation from mixed power sources (Defra, 2005; van Dril and Elzenga, 2005). This figure was used in all calculations of electricity consuming processing steps.

### 7.5. Quality of recycled compounds

It has been shown that post-consumer plastic packaging waste, both from selective collection and household waste sorting, can be recycled into high-value-added compounds at competitive prices (Private communications - Plastinum Polymer Technologies, 2008-2009). It is assumed, therefore, in this study that the recycled compounds produced fully replace virgin resins.

### 7.6. Virgin polyolefin production

Data for the virgin polyolefin production are derived from the eco-profiles of Plastics Europe (formerly Association of Plastics Manufacturers in Europe, APME). The data represent European averages collected from a number of plants in 1999. The APME methodology is described by Boustead (2005) and data sources are described in the individual eco-profiles.

In principle, the eco-profiles are cradle-to-gate, i.e. they cover all steps from raw materials production to the production of polymer resins or granulates, including the transport steps between processes. The production process requires the following steps for polyolefins (Boustead, 2005):

- extraction of oil and natural gas
- transport from oilfields to refineries (pipeline or tanker dependent on the source)
- refining the crude oil, the fraction of interest is the naphtha fraction (approx. 12 wt% of the yield but subject to differences)
- cracking of naphtha and natural gas to ethylene, propylene, butene and other by-products
- ethylene and propylene is transported to polymerisation facilities for the final production of the polyolefin
- production of resins through polymerisation

A specific report on the calculation of electricity production is also provided (Boustead, 2005).

For the generation of Eco-profiles, especially five areas of concern regarding the data quality are addressed in the methodology paper published by the Plastics Europe: complexity of plant, accuracy of records, format of records, the sharing of common facilities and the problem of missing data. These are explained in (Boustead, 2005). A specific problem for complex plants producing several products like the refineries and the cracking is how to allocate the environmental impacts of the plants to the different products produced. For refineries this allocation has been made on the basis of energy content of the products, whereas for the cracker the allocation is based on mass of the products (Boustead, 2005).

Data on oil refining have been obtained from two separate sources: direct returns from seven oil refineries and world data from the IEA (International Energy Agency) statistics. Data for cracking is derived from 17 crackers (out of a total of 50 crackers in Europe in 1999) all of which supplier of the petrochemical industry. Data for HDPE cover approx. 90% of the total European production. For LDPE and PP, the corresponding figures are 94% and 77%, respectively.

#### 7.7. Composition of household plastic packaging waste

The average composition of plastics contained in Dutch household waste is shown in Table 1. The total plastic content of the Dutch household waste is approx. 14 wt-% (Krutwagen and van Ewijk, 2008).

Rigid non-packaging plastics make up almost 1/3 of the plastics found in Dutch household waste, as shown in the Table 1.

These plastics are not covered by existing separate collection schemes, but can be easily

recovered in waste sorting. Further, the above table underpins the importance of recovering as much foils as possible when the environmental impact of recycling is to be minimized.

**Table 1.** Average composition of plastics (both packaging and non-packaging) contained in Dutch household waste (Krutwagen and van Ewijk, 2008).

Type	Share [wt-%]
<i>packaging plastic</i>	
foils	54
flacons	9
large bottles (>0.5 l)	6
small bottles (≤0.5 l)	1
<i>non-packaging plastic (rigids)</i>	30
<b>total</b>	<b>100</b>

## 8. Results

According to

Table 2, the gross carbon dioxide emission associated with the production of virgin polyolefins from crude oil lies between 1569 and 1687 kg CO<sub>2</sub>/ton resin. The presented figures were calculated from data published by Plastics Europe (Boustead, 2005), see also the Methodology and Assumptions section for more details.

As shown in **Error! Reference source not found.** and **Error! Reference source not found.**, the share of transport in the carbon dioxide emission increases from 5% in the waste sorting route to 18% in the selective kerbside collection route. This is mainly due to the low bulk density of the unprocessed plastic packaging waste (approx. 150-200 kg/m<sup>3</sup> when slightly compressed in the waste collection lorry, according to our estimate).

The transport distances between processing facilities shown in **Error! Reference source not found.** represent rough estimates by assuming four integrated plastic recycling facilities to treat an equilibrium amount of 120 kton/a selectively collected plastic packaging waste in The Netherlands. Note that a large portion of foils currently collected in the German DSD programme is converted into mixed agglomerates (mainly LDPE, some HDPE and PP, often contaminated with aluminium and paper). This mixed foil fraction is either used as RDF or applied in large-cross-section products (plastic lumber). It is questionable in the latter case if these recycled plastics actually replace virgin resins.

**Table 2.** Breakdown of carbon dioxide emissions associated with the different steps of producing virgin polyolefins from crude oil as calculated from data of Plastics Europe (Boustead, 2005).

Resin type	Fuel production	Fuel consumption	Transport	Process	Biomass	Total
HDPE	420	950	8.8	190	-0.002	1569
LDPE	580	960	7.3	140	-0.01	1687
PP	350	910	8.1	400	-0.002	1668

unit of measure: kg CO<sub>2</sub>/ton resin**Table 3.** Breakdown of carbon dioxide emissions associated with the different steps of producing recycled polyolefins (HDPE, LDPE and PP) from plastic packaging waste through household waste sorting

	<i>Av. traveling distance (km)</i>	<i>Specific CO<sub>2</sub> emissions (kg CO<sub>2</sub>/km)</i>	<i>Net truck load (ton)</i>	<i>Power consumption (kWh/ ton)</i>	<i>Absolute CO<sub>2</sub> emission (kg CO<sub>2</sub>/ton)</i>
Road transport in waste collection					
Kerbside collection route	7	10.5	8.5	-	9
Transport to waste sorting plant	43	0.789	8.5	-	4
Processing at waste sorting plant (excluding fermentation)	-	-	-	7.5	4
Road transport to plastic recycling plant in compression container	5	0.789	20	-	0.2
Processing at plastic recycling plant					
Pre-treatment (cutting, washing, drying etc.)	-	-	-	200	108
Extrusion/compounding	-	-	-	240	130
<b>Total</b>					<b>254</b>

**Table 4.** Breakdown of carbon dioxide emissions associated with the different steps of producing recycled polyolefins (HDPE, LDPE and PP) from plastic packaging waste through selective kerbside collection

	<i>Av. traveling distance (km)</i>	<i>Specific CO<sub>2</sub> emissions (kg CO<sub>2</sub>/km)</i>	<i>Net truck load (ton)</i>	<i>Power consumption (kWh/ ton)</i>	<i>Absolute CO<sub>2</sub> emission (kg CO<sub>2</sub>/ton)</i>
Road transport in waste collection					
Kerbside collection route	7	10.5	2.5	-	29
Transport to regional transfer station	40	0.789	2.5	-	13
Transport to NIR sorting plant	80	0.789	8	-	8
Processing at NIR sorting plant	-	-	-	20	11
Road transport to plastic recycling plant	100	0.789	20	-	4
Processing at plastic recycling plant					
Pre-treatment (cutting, washing, drying etc.)	-	-	-	200	108
Extrusion/compounding	-	-	-	240	130
<b>Total</b>					<b>302</b>

## 9. Conclusions

The Dutch discard a pro-capita amount of 40 kg/y of plastics into their household waste. At present, waste treatment facilities in the Netherlands provide three different options for applying this resource: (E) energy recovery in MSWI's, (C) selective collection and mechanical recycling, and (S) separation from mixed household waste followed by mechanical recycling.

Comparison of the alternatives shows that, with the latest extrusion technology used at industrial scale, route S is the most interesting option. On a per capita basis, Route S is able to recover 20 kg/y of secondary plastics of primary-replacing quality with no additional kerbside collection. Compared to route E, the extra processing needed for this option amounts to 5 kg/y of CO<sub>2</sub>, whereas 32 kg/y of CO<sub>2</sub> are saved on the production of primary plastics and 35 kg/y of CO<sub>2</sub> are saved as a net result because on the one hand less waste plastics is incinerated at the MSWI (-63 kg/y of CO<sub>2</sub>) but on the other hand less electricity is produced (+28 kg/y of CO<sub>2</sub> to compensate for the electricity by other producers).

Route C is less attractive than route S, mainly because less plastic become available for recycling, but also because it delivers a problematic material quality and involves more kerbside logistics. Per capita, this option produces an extra 3 kg/y of CO<sub>2</sub> in processing, whereas 16 kg/y of CO<sub>2</sub> are saved on the production of primary plastics and 18 kg/y of CO<sub>2</sub> are saved at the MSWI

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